

**REPORT DOCUMENTATION PAGE**

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1204 Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE

AFRL-SR-BL-TR-02-

uding  
ray, Suite

1. REPORT DATE (DD-MM-YYYY)  
10/01/01

2. REPORT TYPE  
Final Progress Report

3. DATES COVERED (From - To)  
9/1/97 to 06 / 30/01

4. TITLE AND SUBTITLE  
3D Digital data-storage using Two-Photon process :A Demonstration task /  
Novel multifunctional chromophores for electro-optic and other photonics applications

5a. CONTRACT NUMBER

6b. GRANT NUMBER  
AFOSR F49620-97-1-0529

5c. PROGRAM ELEMENT NUMBER  
62173C

5d. PROJECT NUMBER  
1651

5e. TASK NUMBER  
05

5f. WORK UNIT NUMBER

6. AUTHOR(S)  
Dr. Paras N. Prasad

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  
Research Foundation of SUNY,  
PO Box-9,  
Albany, NY-12201-0009..

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  
AFOSR/NL  
801 N. Randolph St. Rm 732  
Arlington, VA 22203-1977

10. SPONSOR/MONITOR'S ACRONYM(S)

AIR FORCE RESEARCH  
NOTICE OF TRANSFER OF  
HAS BEEN REVIEWED AND IS APPROVED FOR PUBLIC RELEASE  
LAW AFR 190-12. DISTRIBUTION IS UNLIMITED.

12. DISTRIBUTION / AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

**14. ABSTRACT**

New opto-electronic and composite materials with enhanced photonic performance were developed and their applications in 3D optical data-storage, 3D optical-circuitry, 3D micro-fabrications and photorefractivity were studied. Two-photon based technology was used to do photo-crosslinking at a precise volume location to produce complex 3D optical-circuitry such as waveguide splitters and grating couplers as well as for fabricating MEMS. Another area of our activity has been in preparation of photonic band gap materials for visible and near-IR range. Highly monodispersed silica and polystyrene spheres of varying diameters (100-800nm) were prepared and photonic crystals made from them showed photonic pseudogaps. We have successfully infiltrated the pores with a high refractive index conjugated polymer, PPV and etched out the silica spheres. The resulting inverted photonic crystal exhibits enhanced reflectance at the band gap. Using a new approach of photosensitization with nanocrystallites of inorganic semiconductors, we have prepared photorefractive composite for operation at 1.31µm and this approach can be extended for preparation of photorefractive materials with a tailored spectral response. Our new materials development in collaboration with Wright lab has made it possible to use two-photon approach to write information in different layers with the capacity of terabits/cm<sup>3</sup>, which can now be read by using a simple CW green laser. A three dimensional digital data-storage system based on two-photon process also was demonstrated. We have written layers of digital data in a dye doped polymer media (AF-240 from Air force Polymer branch doped in PMMA) using highly localized two-photon process. We have demonstrated a new data read back system using a 532nm solid state laser and were able to read the data using confocal single photon fluorescence detection.

**15. SUBJECT TERMS**

16. SECURITY CLASSIFICATION OF:

a. REPORT

b. ABSTRACT

c. THIS PAGE

17. LIMITATION OF ABSTRACT

18. NUMBER OF PAGES

19a. NAME OF RESPONSIBLE PERSON

19b. TELEPHONE NUMBER (Include area code)

20020206 097

**Abstract:**

New opto-electronic and composite materials with enhanced photonic performance were developed and their applications in 3D optical data-storage, 3D optical-circuitry, 3D micro-fabrications and photorefractivity were studied.

Two photon process based approach has allowed us to use photo-crosslinking at a precise volume location to produce complex 3D optical-circuitry such as waveguide splitters and grating couplers as well as for fabricating MEMS. Another area of our activity has been in preparation of photonic band gap materials for visible and near-IR range. Highly monodispersed silica and polystyrene spheres of varying diameters(100-800nm) were prepared and photonic crystals made from them showed photonic pseudogaps. We have successfully infiltrated the pores with a high refractive index conjugated polymer, PPV and etched out the silica spheres. The resulting inverted photonic crystal exhibits enhanced reflectance at the band gap. Using a new approach of photosensitization with nanocrystallites of inorganic semiconductors, we have prepared photorefractive composite for operation at 1.31  $\mu\text{m}$  and this approach can be extended for preparation of photorefractive materials with a tailored spectral response.

Our new materials development in collaboration with Wright lab has made it possible to use two-photon approach to write information in different layers with the capacity of terabits/cm<sup>3</sup>, which can now be read by using a simple CW green laser. A three dimensional digital data-storage system based on two-photon process also was demonstrated. We have written layers of digital data in a dye doped polymer media (AF-240 from Air force Polymer branch doped in PMMA) using highly localized two-photon process. We have demonstrated a new data read back system using a 532nm solid state laser and were able to read the data using confocal single photon fluorescence detection.

**DISTRIBUTION STATEMENT A**

Approved for Public Release  
Distribution Unlimited

### 3D Fabrication:

A novel approach was used for micro-fabrication of three-dimensional optical circuitry using in-situ two-photon assisted polymerization in an as-formed bulk sample. The bulk media consisted of a blend of photo-curable and thermally curable epoxies. 1x2 and 1X4 splitters were fabricated inside the volume and imaged by confocal microscopy. End-fire

#### Stacked Channel Waveguide

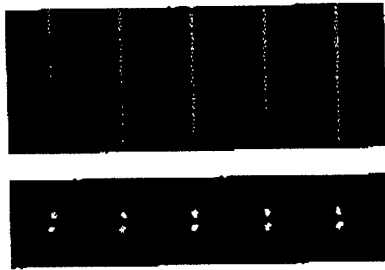


Figure. Confocal microscope images of single-mode channel waveguides which were stacked vertically with a separation of 30  $\mu\text{m}$ .

**Optical Loss = 0.8 dB/cm**  
for a single mode channel waveguide  
(by cut-back method)

#### Output Mode Pattern

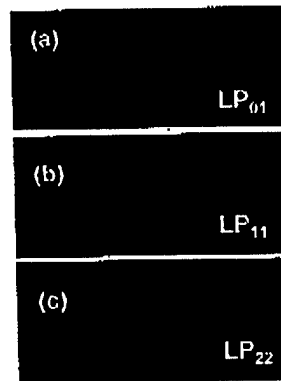


Figure. Near field intensity distributions of guided modes at  $\lambda=632\text{nm}$ . (a) single mode and (b), (c) multi mode channel waveguides.

#### Confocal Microscope Image of 1X4 Splitter



#### Confocal Microscope Image of Cross-section of 1X4 Splitter



#### Output of Guiding Mode ( $\lambda=632\text{nm}$ , HeNe laser)

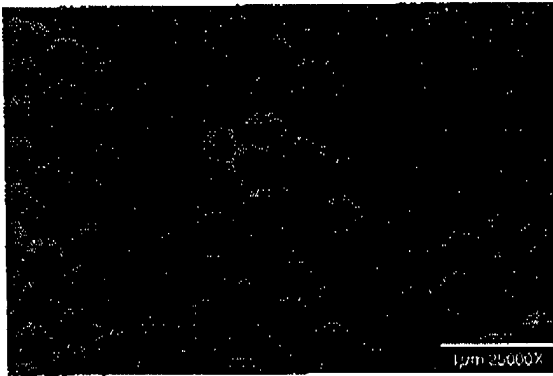


coupling of a He-Ne laser beam into these splitters was also achieved. By controlling the

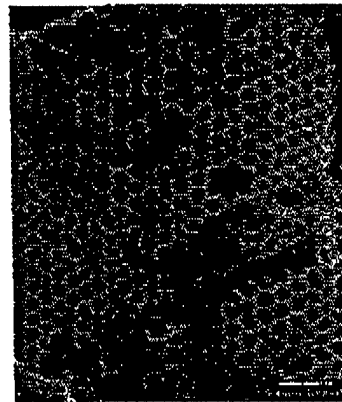
size and shape of the waveguides, we were able to make single mode or multimode waveguides.

## **Photonic Band Gap Materials:**

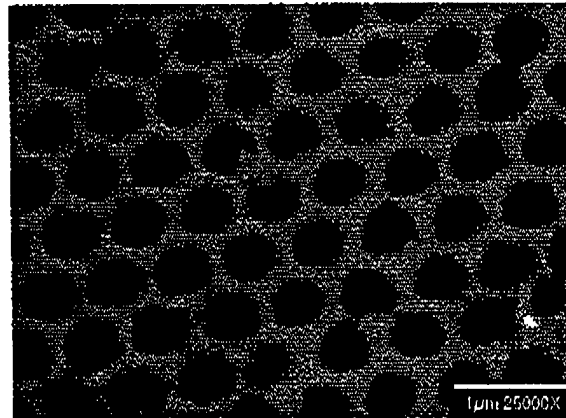
We have achieved successful fabrication of highly monodispersed silica and polystyrene spheres. The size of these spheres can be varied between 100 and 800 nm to allow for proper tuning of the photonic crystal properties. Optical absorption of the silica photonic crystal shows the presence of a photonic pseudogap. The sphere size and thermal treatment can easily control this gap. Strong angular dependent Bragg reflections were also measured. This supports the SEM result that the crystal is packed throughout the bulk. We have successfully infiltrated the pores with PPV and etched the silica spheres. The resulting inverted PPV photonic crystal exhibits enhanced reflectance at the band gap. We have also successfully fabricated inverted titania and polystyrene photonic crystals.



**SiO<sub>2</sub> Photonic Crystal**



**Inverted TiO<sub>2</sub>  
Photonic Crystal**

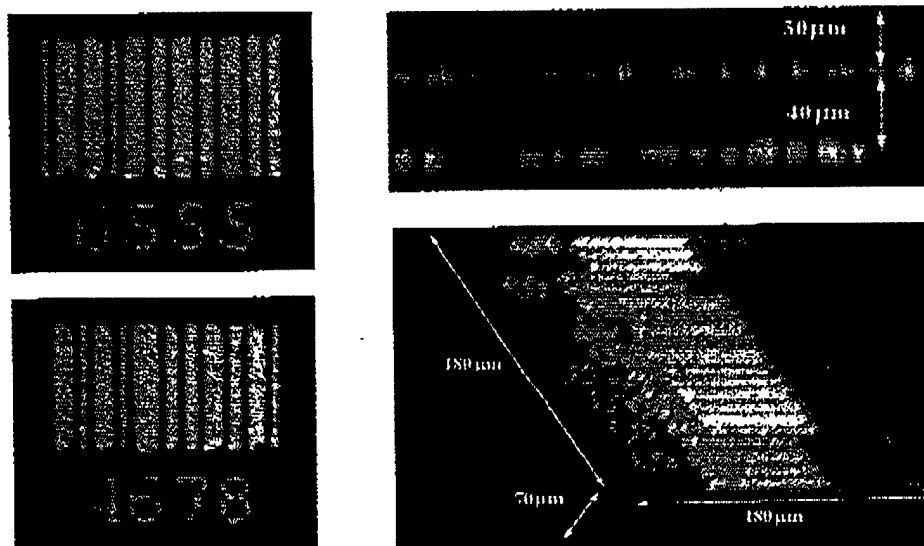


**Inverted  
polystyrene  
Photonic Crystal**

## Optical Data Storage:

We also developed novel photorefractive nano-composites for applications at communication wavelengths. A new approach of using inorganic semiconductor quantum dots of well-defined excitonic resonance for photosensitization was used. These quantum dots were dispersed in a hole trapping polymer containing electro-optic chromophore to prepare the photorefractive nano-composites. Using PbS quantum dots as photosensitizers we demonstrated, to the best of our knowledge first time, photorefractive operation in a polymer composite at  $1.31\mu\text{m}$ .

We have achieved a high density data-storage with gray-scale control in multiple planes as stacked Compact Disks (CDs) at a separation of  $10\mu\text{m}$ , using a polymer block doped with a highly efficient two-photon dye. The absorption and fluorescence of the dye at the written spot shift to a longer wavelength, permitting easy fluorescence mode readout with a linear excitation using an inexpensive laser source.



The storage capacity in this case is estimated to be  $10^{12}$  bits/cm<sup>3</sup>. To demonstrate this technique we used Poly-methyl methacrylate (PMMA) doped with dye AF240 (7-benzothiazol-2-yl-9, 9-diethylfluoren-2-yl) diphenylamine developed at Airforce

Research Laboratory at Dayton, as the storage medium. A tightly focussed pulsed IR beam (A Ti:Sapphire laser operating at 800nm with pulse width 80fs and a repetition rate of 90MHz as light source and a high NA objective for focussing) was used to write barcodes in to the dye doped polymer medium mounted on a computer controlled scanning stage. This way we were able to write multiple layers of barcodes/images in a single polymer block at a vertical separation of 10 microns, and up to a depth of couple of hundred microns. This can be used to make security identification labels with secret identification codes well concealed deep inside the label on in a polymer composite at 1.31 $\mu$ m.

### **Digital Datastorage:**

Extending the above mentioned technique, a digital datastorage, system based on two-photon process also was demonstrated. We have written layers of digital data in a dye doped polymer media (AF-240 from Air force Polymer branch doped in PMMA) using highly localized two-photon process and were able to read the data using confocal single photon fluorescence detection. The data is written into the medium using femto second pulses from a Ti:Sapphire laser tuned to 800nm, and the fluorescence change induced in the medium is detected by single photon confocal detection.

We have demonstrated a new data read back system using a 532nm solid state laser, which shows promise towards the miniaturization of the read back system. These solid state lasers can be compact and inexpensive compared to the bulky gas lasers. We have designed a new fiber coupled read back system and developed new software for this purpose. In the new reader, the single photon fluorescence signal is delivered to a photo multiplier tube using a fiber delivery system. This signal is digitized and analyzed to retrieve the stored digital data. To make the system compatible with the existing CD system, we have adopted an edge detection algorithm, so that any change in fluorescence ( edge of the written bit) will be taken as 1. With this system we are projecting a storage capacity of ~0.3Tb in a CD sized disk with 5mm thickness. The current system works with a writing speed of 1Kb/s and reading speed of ~10Kb/s.

The schematic diagram of the current digital data writer and reader are shown in the figure given below (figure 1 &2 ). A confocal microscope image of the data bits written using this system and a diagram of the signal pattern obtained from the data

reader (figure. 3) with the digital conversion using the edge detection algorithm are shown in the figure 4.

### Approach: Digital Writing

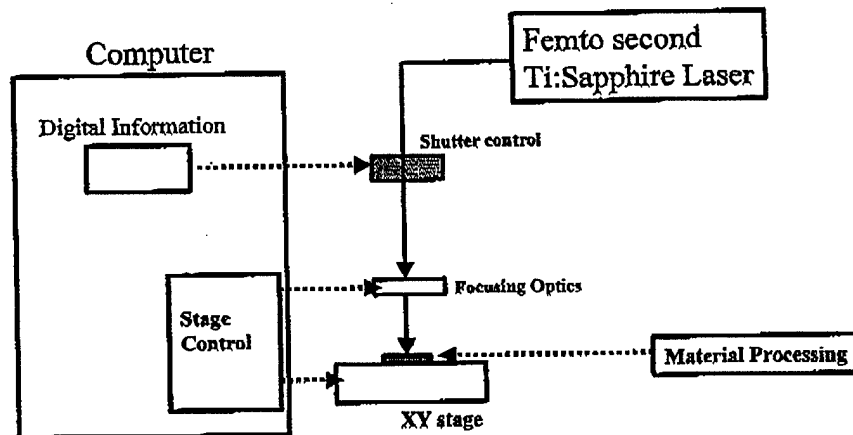


Fig. 1

### Approach: Digital Data Reading

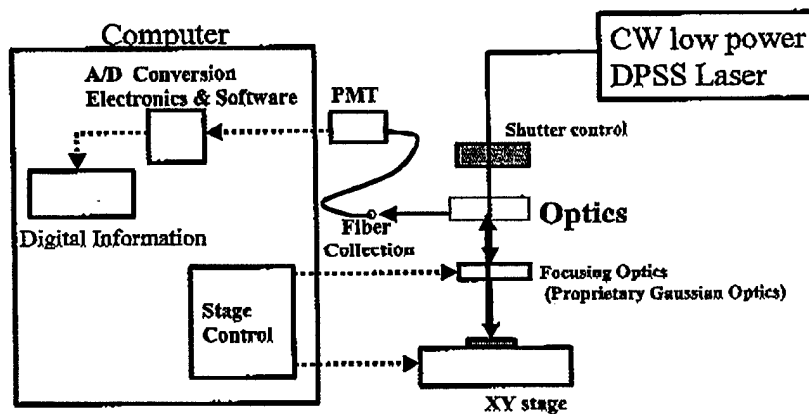
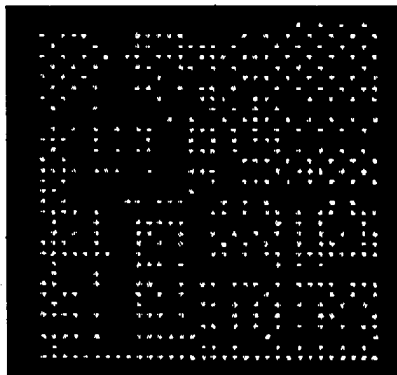
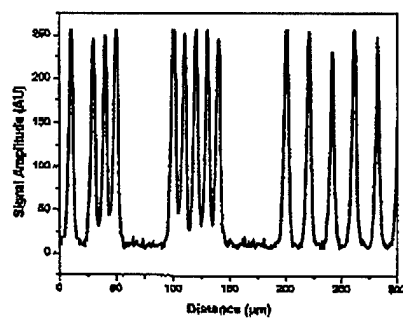


Fig. 2

**Confocal Microscope image of the bit pattern  
Written in polymeric media**

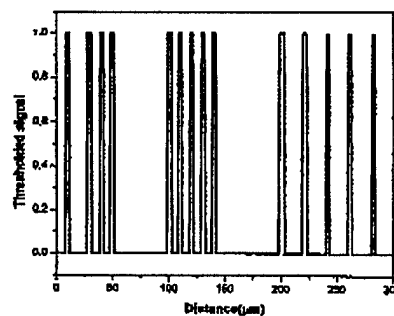


**Fig. 3**



**Original Signal**

**Fig. 4**



**Thresholded signal**

101110000111110000010101001010